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AN EXPERIMENTAL STUDY OF THE ABSOLUTE TEMPERATURE SCALE. I. THE CONSTRUCTION OF SEVERAL TYPES OF PLATINUM RESISTANCE THERMOMETERS.

By James A. Beattie, David D. Jacobus, and John M. Gaines, Jr

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(Contribution from the Research Laboratory of Physical Chemistry, Massachusetts Institute of Technology, No. 241.)

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TABLE OF CONTENTS.

		Page
1.	Introduction	167
2.	Methods of Compensating for Lead Resistance	168
3.	Construction of the Templets	168
4.	Construction and Winding of the Mica Forms	172
5.	The Casings	176
6.	Assembly	176
7.	Materials	179
8.	Annealing	180
9.	The Commutator	180
10.	Summary	183
11.	References	184

1. Introduction.

The ease and precision with which temperatures can be determined and reproduced by use of platinum resistance thermometers have brought this method of measuring temperatures into quite general use. The Siemens[1] resistance thermometer in which the wire was wound on a clay cylinder and enclosed in a wrought iron tube was not satisfactory for use at high temperatures due to contamination of the platinum. In the modern resistance thermometer the wire is wound on a mica frame and enclosed in a glass, quartz, or in special instances, metal sheath. This form of the instrument has given such excellent results in the hands of various investigators that by international agreement[2] the platinum resistance thermometer has been adopted as the instrument for the interpolation of temperatures on the thermodynamic scale between $-$ 190° C. and $+$ 660° C.

Three types of supporting frames are in general use: the Callendar[3] mica-cross, the Bureau of Standards calorimetric,[4] and the Bureau of Standards strain-free.[5] The calorimetric, or flat, thermometer was designed for calorimetric measurements and has a very small time lag in responding to thermal changes; the strainfree type is so

constructed that the platinum wire cannot be subjected to mechanical strain as the wire expands and contracts on the mica form due to the heating and cooling of the thermometer. A detailed description of a method for constructing the calorimetric and strainfree types has been given by Sligh.[6]

During the course of an investigation of the absolute temperature scale methods of construction that are especially useful when several thermometers of one kind are to be made have been devised for each of the three types of windings. Some minor changes in design have been introduced. These are described in the present paper.

All of the resistance thermometers for which the methods of construction are given had a resistance at 0° C. of about 25.5 ohms and were wound with 0.1 mm. platinum wire, it requiring about 175 cm. of wire for each thermometer.

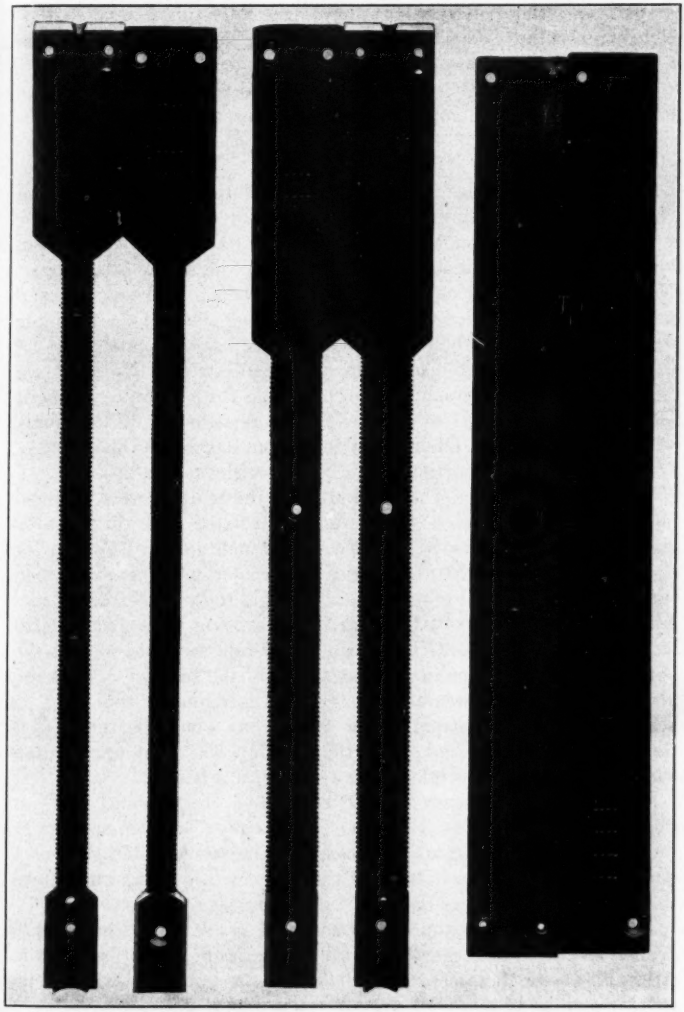
2. Methods of Compensating for Lead Resistance.

Of the three methods of compensation for variation in lead resistance: the Callendar four-lead, the Siemens three-lead, and the potential four-lead type, the latter is most suitable for work of the highest precision since the lead resistance is completely eliminated at all temperatures. All of the thermometers constructed for the present work were of the four-lead potential type and were used in conjunction with a Mueller[7] bridge and a commutator that is described in a later section of this paper.

3. Construction of the Templets.

When several thermometers of one kind are to be made, the use of a templet for the drilling and notching of the mica results in a saving of time and also in cleaner edges for, and more precise spacing of, the holes and notches than are obtained by operating directly on the mica. Photographs of the templets used in the construction of each of the three types of windings are shown in Figure 1 and some of the details of the dimensions are given in Figure 2.

General features. Each templet was made from two pieces of cold rolled steel, each $7\frac{1}{2}$ to 8 inches long by $\frac{3}{4}$ inch wide by $\frac{1}{8}$ inch thick, which were held in alignment by dowels and screws at the top and bottom. Smaller dowels served to hold the sheets of mica in place for drilling and notching. The main dowel pins should fit tightly into their respective sockets to prevent breakage of the fragile drills as they pass through the holes in the top plate of the



Mica-Cross Calorimetric Strain-Free

FIGURE 1. Photograph of the Templets.

templet into those in the bottom plate. Each plate was beveled slightly on its inner edge at one end in order that the top and bottom may be separated more easily.

Drill sizes. Uniform drill sizes were used for the corresponding holes of each of the templets. The holes for the larger dowel pins were drilled with a No. 45 twist drill and those for the smaller pins with a No. 59 drill.

For drilling the holes in the mica to take the 0.1 mm. platinum wire, a 0.008 inch "Improved Mascot" pivot drill was used. The top plate of the templet was drilled to within 0.01 inch of the bottom with a No. 66 drill which is a passing fit for the shank of the pivot drill. The two pieces of the templet were then placed together and an 0.008 inch hole drilled through the remaining metal of the top plate and for a distance of about 0.03 inch into the bottom plate.

The holes for the gold lead-wire were made with a No. 77 twist drill and extended through the top plate and for a distance of about 0.03 inch into the bottom plate. The holes through the top plate were enlarged by a No. 60 drill to within about 0.02 inch of the bottom. For the platinum supporting ring a No. 79 drill was used.

The mica-cross type. The two halves of the templet were fastened together, placed between the centers of a lathe and turned to a diameter of $\frac{7}{16}$ inch for a distance of $\frac{3}{4}$ inch and to $\frac{17}{64}$ inch for a distance of $5\frac{1}{4}$ inches. A series of circular grooves were then cut by means of a tool ground to a 30° angle the point of which was flattened to a breadth of 0.008 inch. The grooves were spaced 0.040 inch apart and were 0.027 inch deep. The tool was held so that the bottom edge was perpendicular to the axis of the templet. Thus the platinum wire which was about 0.004 inch in diameter could not be held tightly in the bottom of the grooves as would be the case if they were V-shaped; and when the winding was held upright the wire rested on a horizontal surface as shown in Figure 2.

Since the platinum wire was to be wound "non-inductively" on the mica frame, a series of circular grooves gives an even spacing of the angle of the wire front and back, and has the advantage over a double thread that the bottom of the templet can be advanced into the collet of the lathe as the grooving progresses.

Immediately at the top of the series of grooves, two holes were drilled for threading the final turn of platinum wire through the strip and above these a series of holes for the gold lead-wire. The spacing and use of these holes are shown in Figure 2.

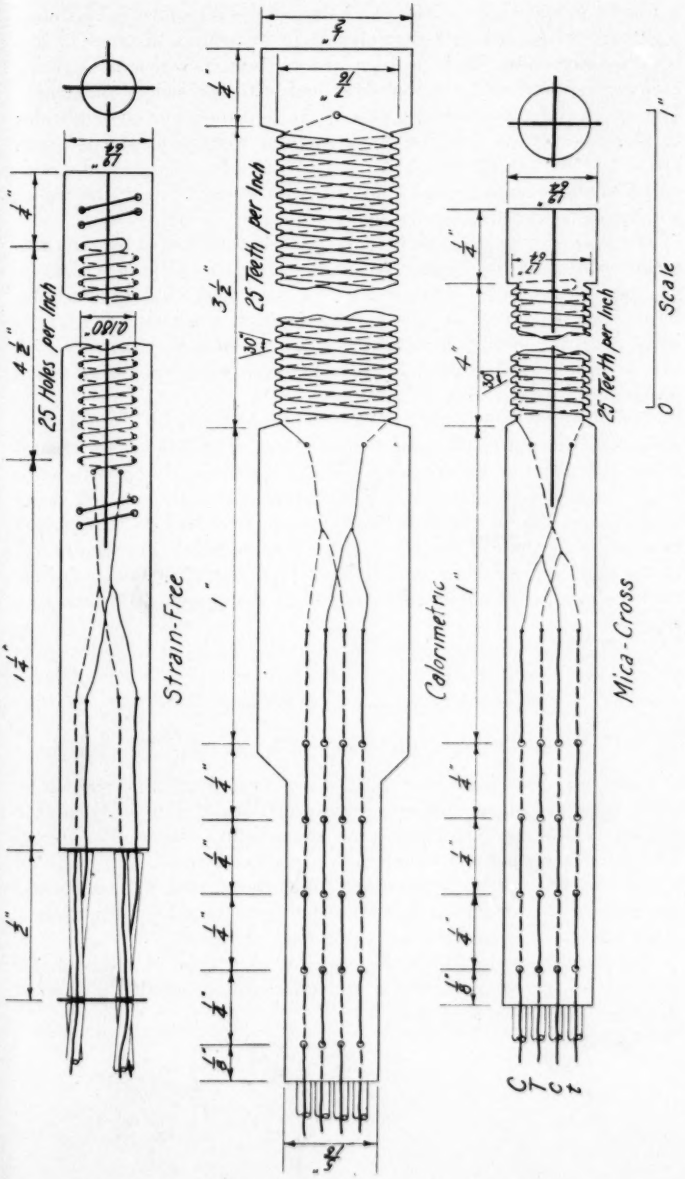


FIGURE 2. Details of the mica forms.

The calorimetric type. The two halves of the templet were fastened together and turned to a diameter of 7/16 inch for a distance of 5¼ inches. Beginning ¾ inch from the bottom, a series of circular grooves were cut with the tool described in the preceding paragraph. For this templet however the axis of the tool was held perpendicular to the axis of the templet. The grooves were spaced 0.040 inch apart and were 0.027 inch deep. Two holes for the platinum wire and a series of holes for the gold lead wire were drilled in the top of the templet, spaced as shown in Figure 2.

The strain-free type. The first templet for this type of winding was made by Mr. Harold Benner of Crufts Laboratory, Harvard University, and our templet was modeled in part after that designed by him. The drilling of so many holes through steel with the fragile pivot drill was greatly facilitated by the use of a very sensitive yet simple drill press designed by Mr. Benner, the castings for which he kindly made available to us.

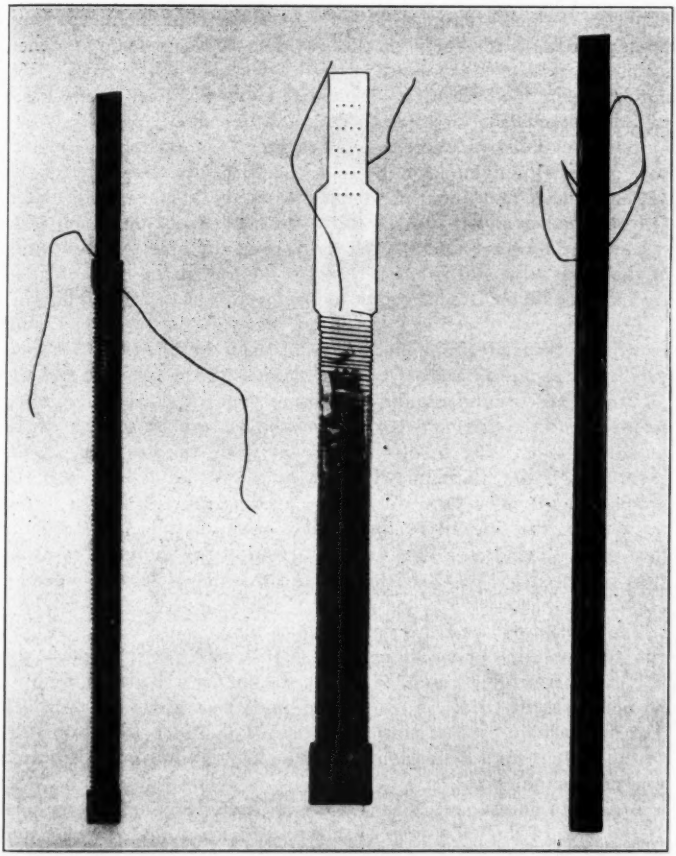
Two rows of holes each 5 inches long and 0.180 inch apart were drilled in the upper plate of the templet. The holes were spaced 0.040 inch apart and corresponding holes were directly opposite each other. They were first spotted in a small lathe, the spacing being obtained by use of the cross-feed, and then drilled to within 0.01 inch of the bottom of the plate with a No. 66 drill. The two halves of the templet were then fastened together and the 0.008 inch hole drilled through the upper plate and for a distance of 0.03 inch into the lower plate.

In the earlier thermometers of this type the gold lead wire was attached as shown in Figure 2, but in a later type a series of holes spaced as shown for the mica-cross type was used.

4. Construction and Winding of the Mica Forms.

The mica used was clear India mica free from iron stains. A piece of appropriate thickness was selected and the blank of the desired type accurately laid out on the strip by means of a needle. The mica was clamped between two pieces of brass, the edges of which were flush with the line along which the cut was to be made and the mica cut first from one side and then from the other with a safety razor blade.

The dimensions to which the mica for each type of thermometer was cut are given in Figure 2 and photographs of the completed windings are shown in Figure 3.



Mica-Cross Winding | Calorimetric Winding | Strain-Free Winding

FIGURE 3. Photograph of the Windings.

Mica-cross type. Two mica blanks each about 0.010 inch thick were prepared: one, which was to be the main strip, being cut to the dimensions given in Figure 2; and the other, the cross strip, being a

duplicate of the bottom portion of the main strip but 4½ inches long. Each piece was placed between the halves of the templets and notched by means of a hack saw blade ground to exactly fit the groove, 100 notches being made in each edge. The blade was drawn across the mica in the opposite direction to that used in ordinary sawing.

In the main strip were drilled the holes for anchoring the last turn of the winding and for the gold lead-wire. In the center of the 4½ inch strip, and about 2¼ inches from the bottom of the main strip, a small hole was drilled and a thin slot about 0.01 inch wide cut along the center line of each strip, from the hole to the bottom of the main strip and from the hole to the top of the cross strip so that they could be fitted together to form a cross as shown in Figure 4.

The cross was placed in a quartered mandrel (as shown in Figure 4) which was made from four pieces of angle brass. A small glass capillary was laid in each of the four grooves of the mandrel and the platinum wire wound around the form. The capillaries were then removed and the thermometer wire pressed flat against the face of the mandrel, which was finally withdrawn from the winding. Thus even though the platinum wire was pulled rather tightly into the grooves of the mica form during the winding process, it was forced away from the bottom of the grooves when flattened against the face of the mandrel. This process accomplishes the same result as that proposed by H. C. Dickinson and mentioned in the paper by Sligh.[6]

The calorimetric type. A piece of mica about 0.012 inch thick was cut to the appropriate dimensions. It was placed between the halves of the templet, notched as described in the previous paragraph, 86 notches being made on each edge, and the various holes drilled. Two insulating strips of mica each about 0.006 inch thick were cut to the same overall dimensions as the main strip, but no indentation was cut for notching.

A piece of mica about ¼ inch wide was placed at the front and one at the back of the main strip as shown in Figure 4, and the platinum wire wound in the grooves. The two mica strips were then removed and the wire pressed flat on the form thus forcing the wires away from the bottom of the grooves.

The insulating strips were placed, one on each side of the main strip, and attached to it by wires at the top and the bottom.

The strain-free type. Two pieces of mica one about 0.010 inch and the other about 0.006 inch thick were prepared, the former being

cut to the dimensions given in Figure 2 and the latter about 1½ inches shorter. Each piece was placed between the halves of the templet and the two rows of holes drilled, 113 holes in each row. There were also drilled at the same time the holes for the supporting rings. In our later thermometers holes were drilled in the longer piece for the gold lead wire, these holes being spaced as shown for the mica-cross type in Figure 2.

From the shorter piece two strips were cut each ⅛ inch wide and each containing along its center line one of the rows of holes. The

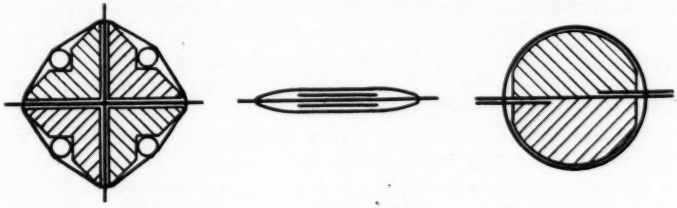


FIGURE 4. Schematic details of the winding process. All views are of sections taken perpendicular to long axis of windings.

main strip and these two spacers were placed between the halves of the winding mandrel, one of the spacers being placed above and one below the main strip as shown in Figure 4. The mandrel was 0.175 inch in diameter by 5 inches long and the edges where the two halves fitted together were slightly flattened to permit easier removal from the winding. The platinum wire was wound around the form, being threaded through the holes every half turn. Care should be taken to allow a loop of sufficient length at the start of the coil to permit the spacer to be moved through 90° after removal of the mandrel.

It was noticed that as the winding progressed the resistance of the wire per centimeter of length increased in a rather even manner. The resistance of the completed winding was in each case about 4% greater than that of the original wire. This is due no doubt to the scraping of fine threads of platinum from the wire as it was pulled through the holes.

When the winding was completed, two supporting rings of 0.3 mm. platinum wire were put into place and welded, the mandrel was

removed, and the spacers moved through 90° and anchored in place by slightly bending the supporting rings.

5. The Casings.

The mica cross and strain free types of windings were designed to fit into the same type of casing which was made of pyrex glass and was about 36 inches long. The head of the casing, see Figure 5, contained four short tubes through which the lead wires were drawn and which were plugged with De Khotinsky cement, and a central tubulature through which the desired gas was introduced into the thermometer and which was finally sealed off. For protection, the glass tube of the casing was usually enclosed, except when being calibrated, in a nickel sheath made from seamless tubing ½ inch outside diameter with 0.020 inch wall.

The casing for the calorimetric type winding was made from seamless nickel tubing 7/16 inch outside diameter with 0.020 inch wall. A portion of the tube about 6½ inches long was flattened on a form by a method suggested by Dr. F. G. Keyes. The form, which was 0.093 inch thick by 0.525 inch wide and about 7 inches long, was somewhat tapered at one end as shown in Figure 6. The nickel tube was heated to bright redness, the tapered portion of the form inserted, and the tube squeezed on to the form between two jaws, shown in Figure 6, which were held in a vise. The form was driven further into the tube and the process repeated until the desired length of the tube had been flattened. The form was freed from the tube whenever desired by a slight pressure exerted along the rounded edge of the tube by use of a vise.

The head for this sheath was of glass and similar to that used for the other types of winding. A glass tube from the head extended into the nickel case for a distance of about 4 inches and was made tight by De Khotinsky cement.

6. Assembly.

Gold lead-wire. The resistances of the various completed windings were adjusted to about 25.5 ohms at 0° C. Four 0.3 mm. gold lead-wires were threaded loosely through the various holes provided for that purpose. To each one was welded a short piece of platinum wire. Two of these short pieces and one of the free ends of the winding were twisted together tightly, cut off square and welded to form a Y. The three platinum wires should leave the button of

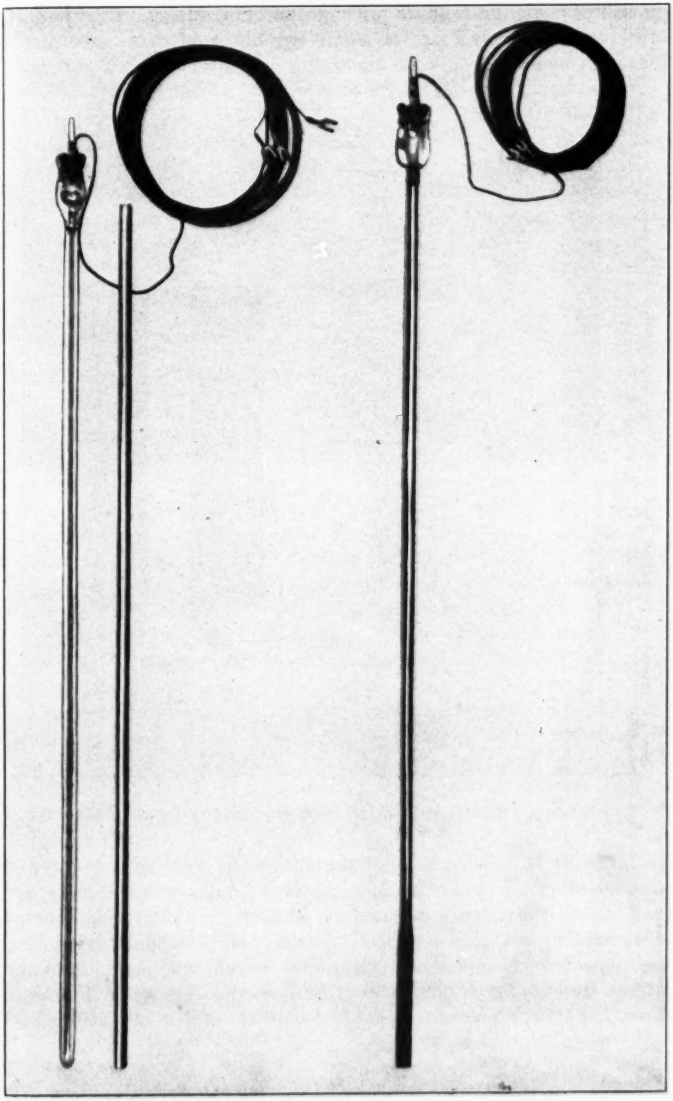


FIGURE 5. Photograph of the Thermometers.

platinum made in welding without additional contact with each other. After the welding was completed the gold wires were pulled through the holes to take up all slack.

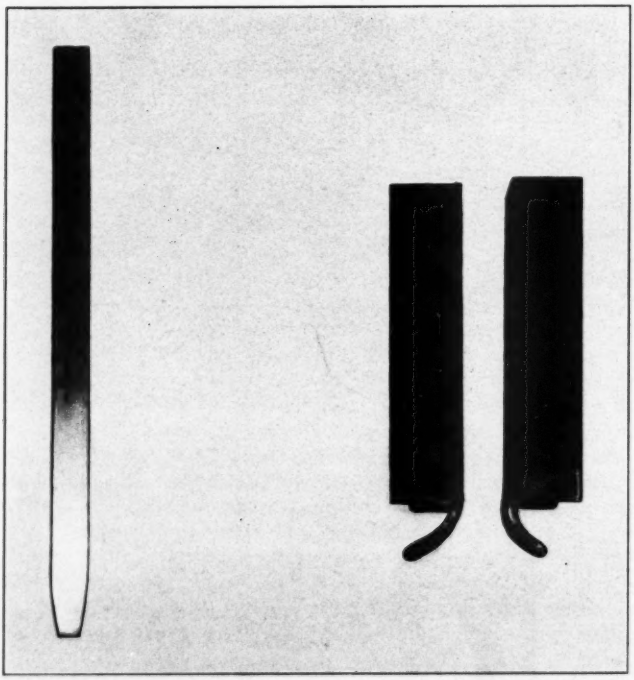


FIGURE 6. Photograph of the Forms for Flattening the Casing.

Insulation of lead-wires. For the mica-cross and strain-free types, a series of pyrex capillaries each ½ inch long were strung on the lead-wire. They were separated by mica spacing discs, which fitted the enclosing tube rather tightly. In this manner about twelve dead air spaces were formed which effectually prevent convection currents. Above these, long capillary tubes were used as shown in Figure 5. No. 24 copper wires were then welded to the upper end of the lead

wire and the winding drawn into the glass case from the bottom. The gold-to-copper weld was just inside the head, the copper wire extending outside through the four tubes which were plugged with De Khotinsky cement. The bottom of the glass case was sealed off and the thermometer filled with the desired gas through the central tubulature, which was then sealed off.

For the calorimetric type, the winding was pulled into the nickel casing with the insulating glass capillaries, which were the length of the nickel casing, inserted over the gold wire. The copper wire was next welded to the gold and the glass head attached.

External lead-wire. The external copper lead-wire was soldered to the four copper wires which projected through the glass tubes of the thermometer head.

Washing. Just before the winding was drawn into the casing, it was washed several times with distilled water.

7. Materials.

Thermometer wire. The platinum wire used was obtained from the Bureau of Standards and had an average temperature coefficient of resistance between 0° and 100° C. somewhat greater than 0.00391. The resistance at 0° C. should be about 25.5 ohms to produce a fundamental interval of 10 ohms, this corresponding to about 175 cm. of 0.1 mm. diameter wire, which size of wire is suitable for all work up to the sulphur boiling point.

Lead-wire. The gold lead-wires which extended from the winding to the head of the thermometer were made of 0.3 mm. diameter wire of 99.96% purity furnished by Baker and Company.

The external wire leading from the thermometer to the commutator was the same as that described by Sligh[6] and was purchased from Leeds and Northrup.

Gas. The majority of the thermometers were filled with commercial nitrogen which had been passed over hot copper and then through a liquid air trap.

Hydrogen was used in one thermometer but it seemed to react with the pyrex glass causing a darkening of the wall. One thermometer was also filled with helium and one with neon. Each of these gases has the advantage when used in a mica-cross or strain-free thermometer that the lag of the thermometers is considerably decreased. However, after several years these thermometers reacted to changes in temperature as slowly as the nitrogen filled ones,

indicating without doubt that the greater part of the gas had escaped, probably by diffusion at the De Khotinsky seals.

The pressure of gas to which the thermometers was filled was about ⅔ atmospheres.

8. Annealing.

At first, it was attempted to anneal the thermometers by successive heating in an air furnace to about 600° C. and cooling in liquid air. Under this treatment the ice points of the flat type thermometer became constant but not those of either other type. The mica-cross and strain-free types were successfully annealed by successive heating in a mixed nitrate bath to about 480° C. and cooling in liquid air. It is believed that there existed a temperature gradient in the air baths which was more or less evenly smoothed by the metal case of the flat thermometers.

Annealing by "flashing" the winding, that is by connecting 110 volts across the terminals of a 25 ohm thermometer for a few seconds, did not yield good results in our hands.

9. The Commutator.

A commutator for connecting any one of four potential-type resistance thermometers to a Mueller bridge has been described by Mueller.[7] In the present work it was desired to use more than four thermometers and for this purpose the commutator shown in Figures 7 and 8 was made. It permits any one of twenty-four resistance thermometers to be connected to the bridge and can be extended to any desired number. By use of the reversing switch, "direct" and "reverse" readings of resistance can be made, the arithmetic average of which give the true resistance of the thermometer coil from one Y weld to the other, the lead resistance being completely cancelled up to the reversing switch. The wire connecting the switch to the bridge was made as short as possible and of 10 gage copper.

The commutator consisted of a rack which holds the thermometer terminal pieces; a universal contact piece which can be rather quickly attached to any one of the terminal pieces and which completes the circuit from the thermometer to the reversing switch; and a reversing switch which interchanges the connections between the bridge and the thermometer leads in a manner which can readily be seen from Figure 7 in which the bridge is shown schematically.

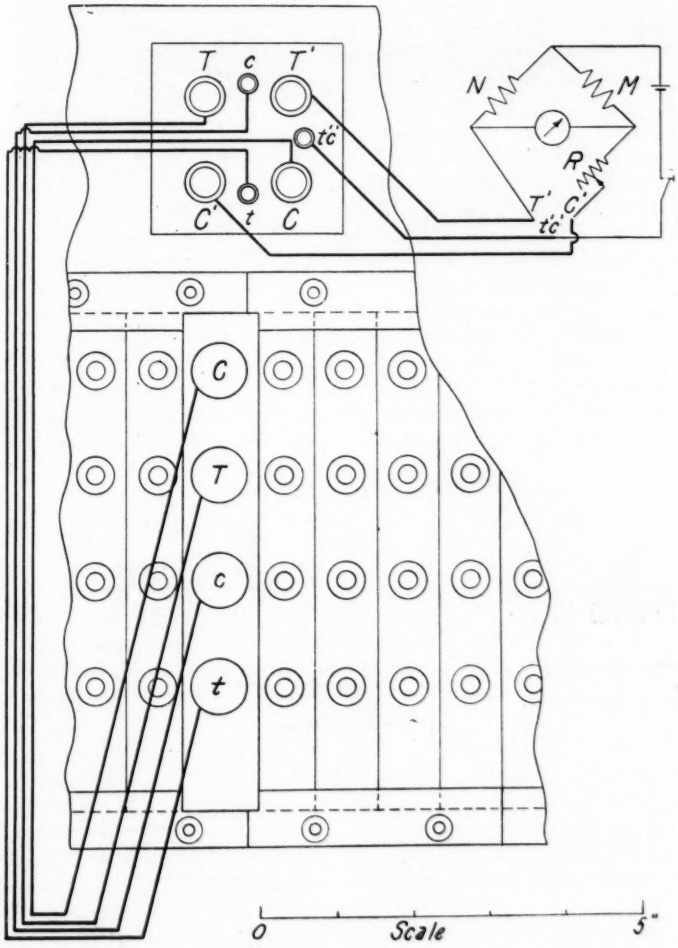


FIGURE 7. Plan view of the commutator.

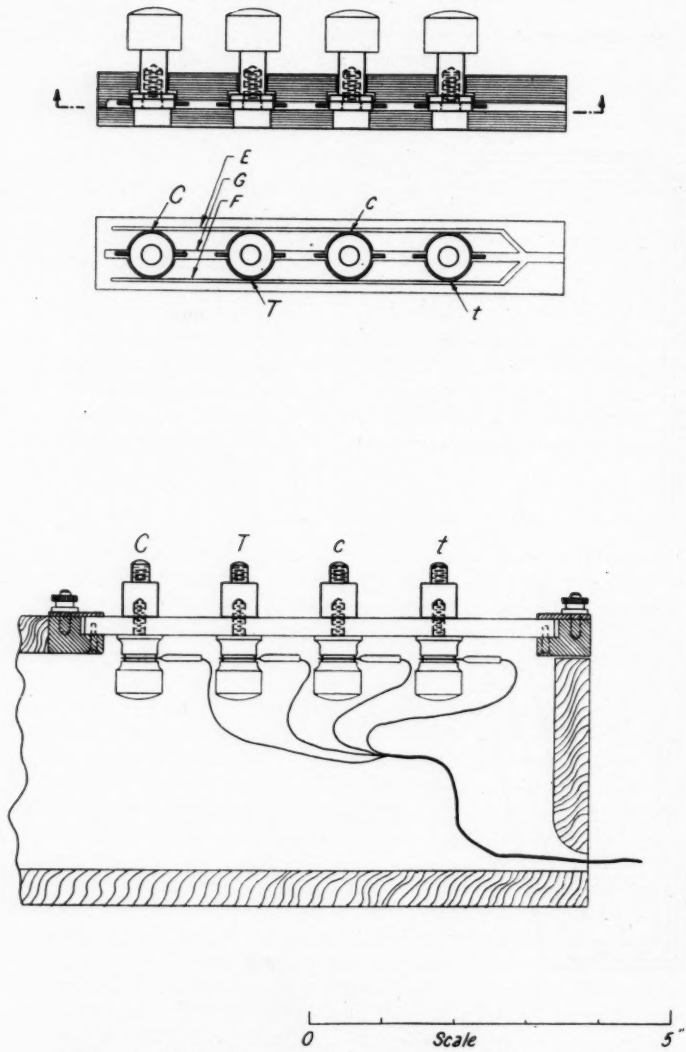


FIGURE 8. Universal contact piece and thermometer terminal piece.

Thermometer terminal piece. For each resistance thermometer there was a terminal piece which consisted of a Bakelite strip 6½ inches by 5/16 inch by ¼ inch. In each strip were mounted four binding posts the bases of which were screwed into nickel-plated brass terminals as shown in Figure 8. It is advantageous to have the upper portions of these terminals threaded with a double thread.

Universal contact piece. The body of this piece was made of two strips of Bakelite which, when attached to each other by screws, held and centered the four contact pieces (see Figure 8). The grooves E and F permitted the lead wire to be conducted to the four contact pieces C, c, T and t, which consisted of nickel-plated brass discs each of which contained two small pins. These pins rested in the groove G and prevented the discs from turning. The hole in the center of each contact disc was large enough to slip readily over the thread of the thermometer terminal studs. Above each disc was a knob containing a threaded hole. When the universal contact piece was fitted over the thermometer terminal piece and the four knobs tightened, the brass discs were pressed tightly against the faces of the corresponding studs.

The discs in the universal contact piece had sufficient "play" in their sockets so that the connection to the terminal piece could be readily made.

Rack and reversing switch. The rack, a plan of which is shown in Figure 7 and a cross section in Figure 8, held the thermometer terminal pieces in place so that the universal contact piece could be readily connected to any one. This put the desired thermometer in direct contact with the bridge through the reversing switch shown in Figure 7 and described by Mueller.[7]

10. Summary.

Details of the construction of 25 ohm platinum thermometers are described. This includes the construction of templets for drilling and notching the mica, the methods of winding the wire on the forms, the construction of the sheaths, and the assembly of the parts. These details are given for the mica-cross, the calorimeteric, and the strain-free type resistance thermometers.

A commutator for connecting any number of potential-terminal type resistance thermometers to a Mueller thermometer bridge is described.

11. References.

[1] Siemens, Proc. Roy. Soc. London, *19*, 443 (1871).
[2] See Burgess, Bureau of Standards Journal of Research, *1*, 635 (1928)
[3] Callendar, Phil. Mag., *32*, 104 (1891).
[4] Dickinson and Mueller, Bulletin of Bureau of Standards, *3*, 641 (1907); ibid., *9*, 483 (1913).
[5] Waidner and Burgess, Bulletin of Bureau of Standards, *6*, 149 (1909)
[6] Sligh, Scientific Papers of the Bureau of Standards, *17*, 49 (1921).
[7] Waidner, Dickinson, Mueller and Harper, Bulletin of Bureau of Standards, *11*, 571 (1915); Mueller, ibid., *13*, 547 (1917).